

Simulation studies in preparation for AWAKE Run 2c

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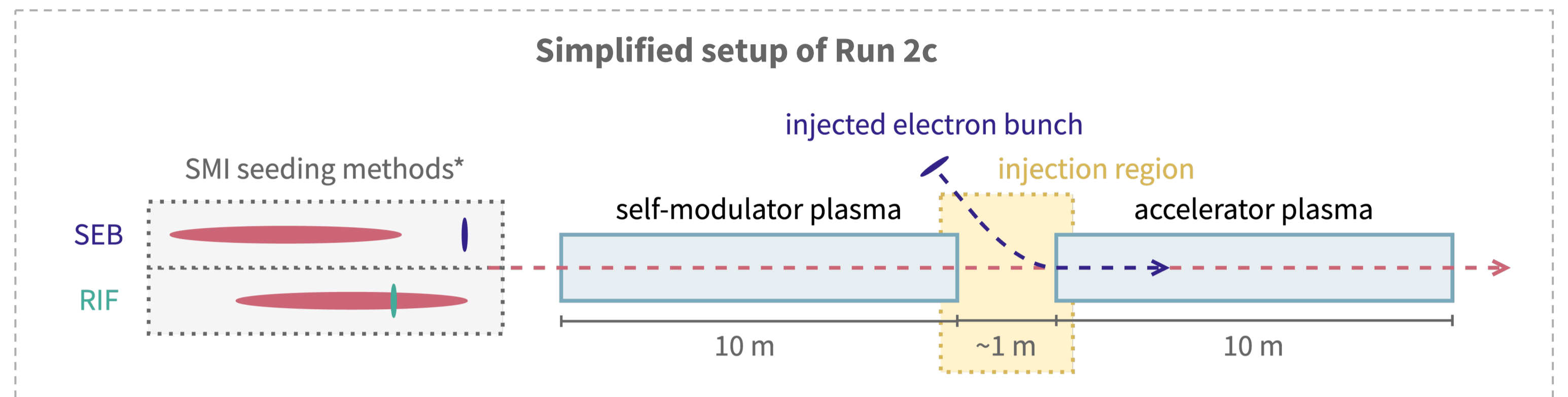
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Introduction

- AWAKE [1] is a plasma wakefield acceleration experiment where the wakefields are driven by a highly energetic, long proton bunch that undergoes the **self-modulation instability (SMI)**
- The main objective of Run 2c (due to start in 2029) is to demonstrate **emittance control** of the accelerated electron bunch
- Particle-in-cell (PIC) simulations are crucial to:
 - contribute to Run 2c design and planning
 - optimize the experiment's parameters
 - provide expectations for the results of Run 2c

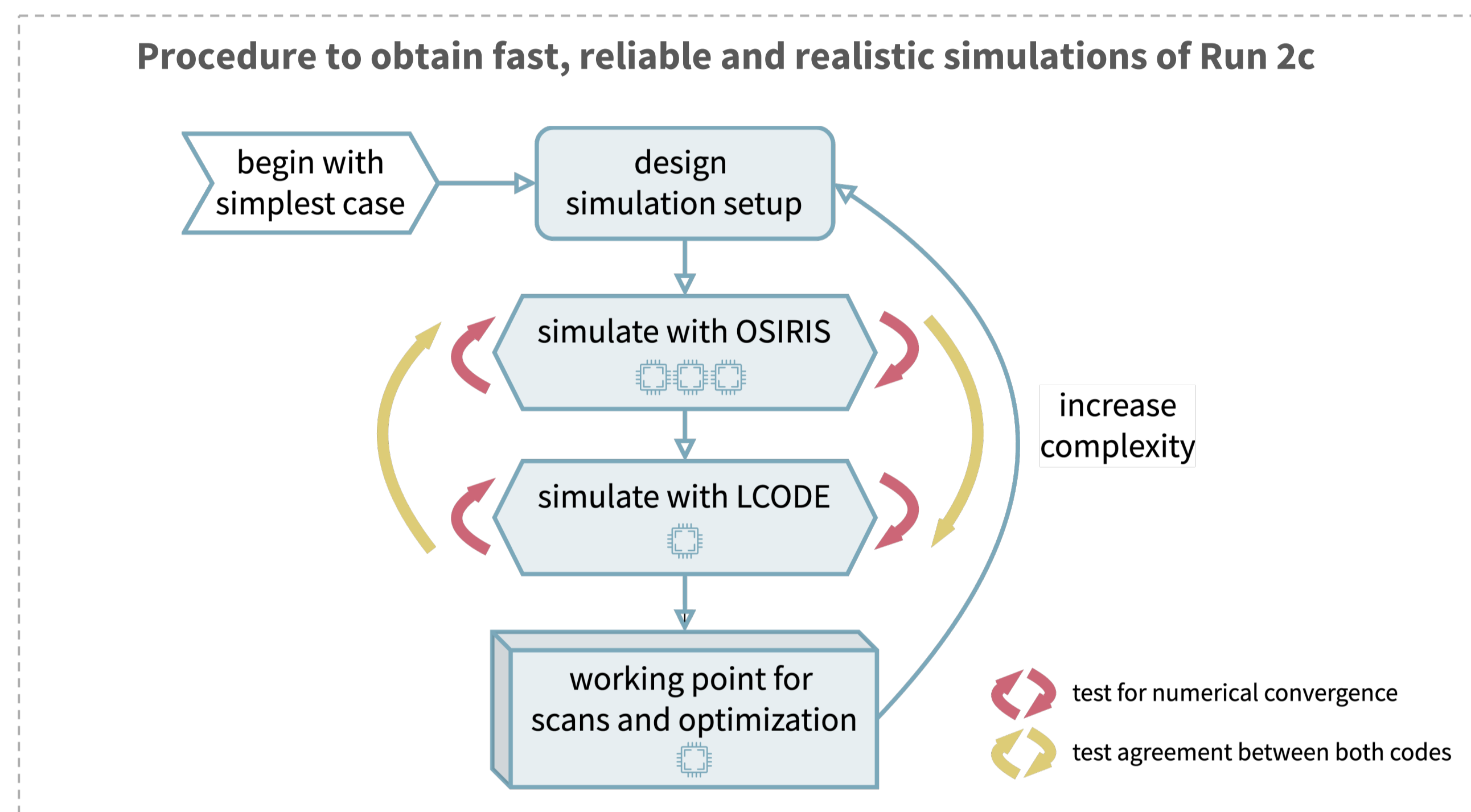
* See "Simulation parameters" section below



Methodology

- Besides encompassing very different spatial scales, simulating the entire Run 2c is challenging since several elements and effects may be important, e.g.:

- matching of the **injected electron bunch** [2]
- implications of different **injection region** designs
- effect of exit density ramp on accelerated bunch



Approximate computational cost of Run 2c simulations

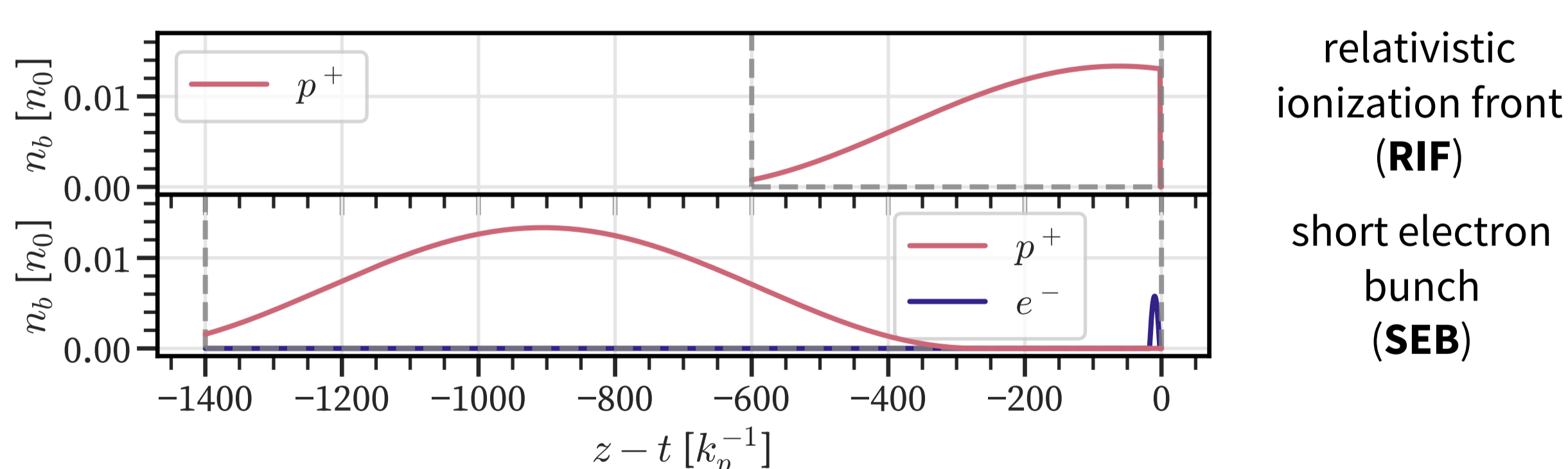
Simulation setup	OSIRIS 2D cyl. (kCPUh)	LCODE 2D cyl. (kCPUh)
RIF seeding	13	0.4
SEB seeding	1000	2–11**

** Cost can be reduced using a substepping technique for the fast-evolving electron driver.

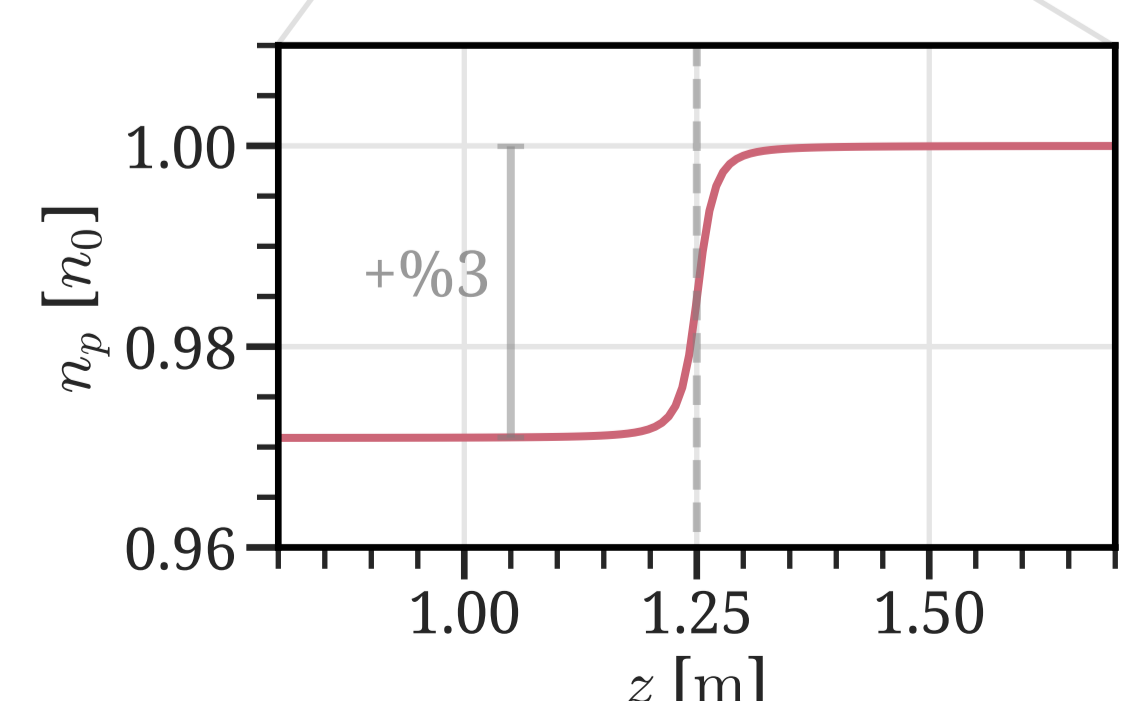
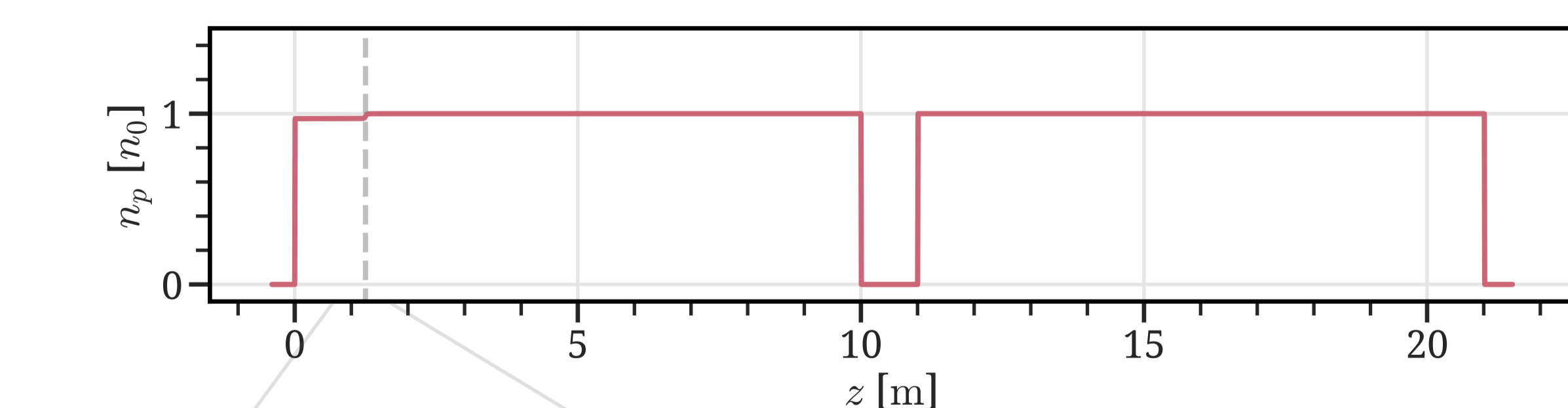
Simulation parameters

Bunch profiles and simulation window

- Two SMI **seeding methods** are considered:



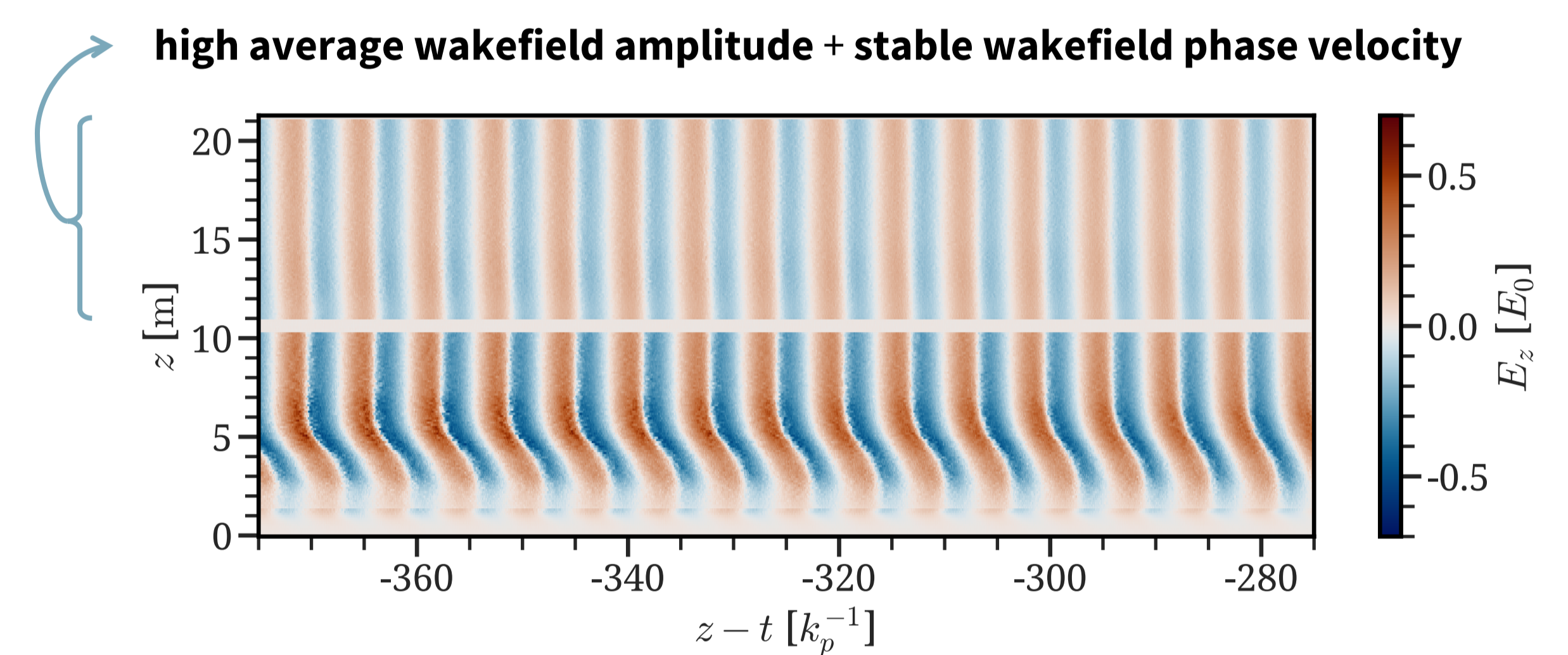
Plasma density profile



- The self-modulator plasma includes a **density step** to achieve higher wakefield amplitudes after SMI saturation [3]

Finding an adequate location for injection (RIF-seeded case)

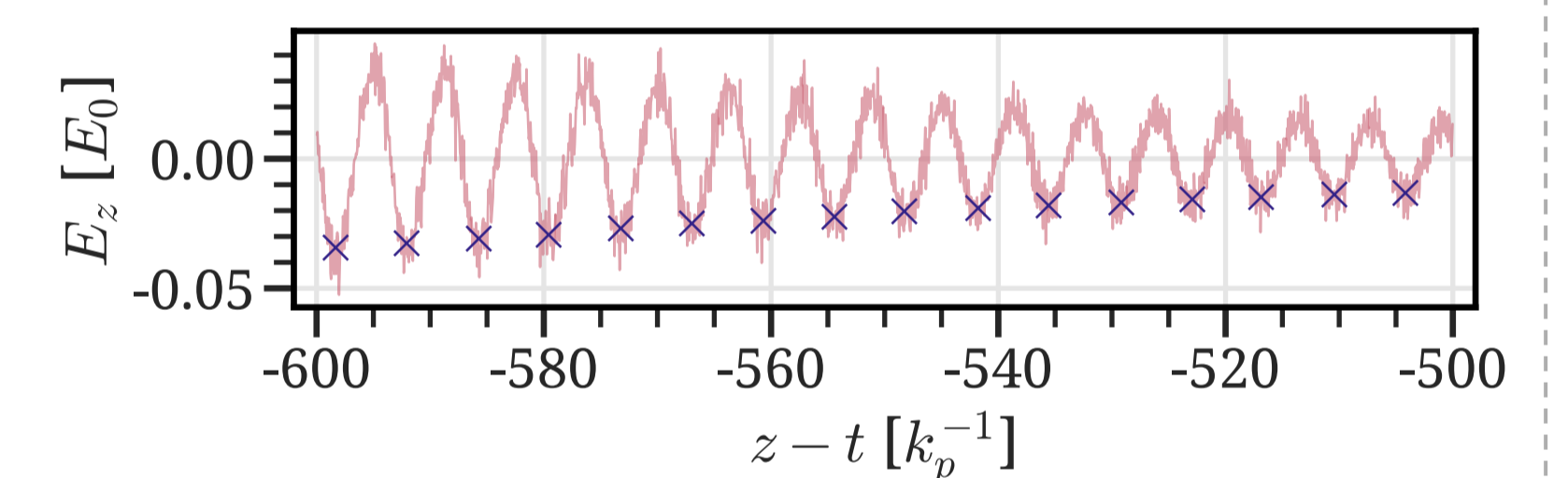
- The location along the bunch for electron injection should fulfil two conditions over the length of the accelerator plasma:



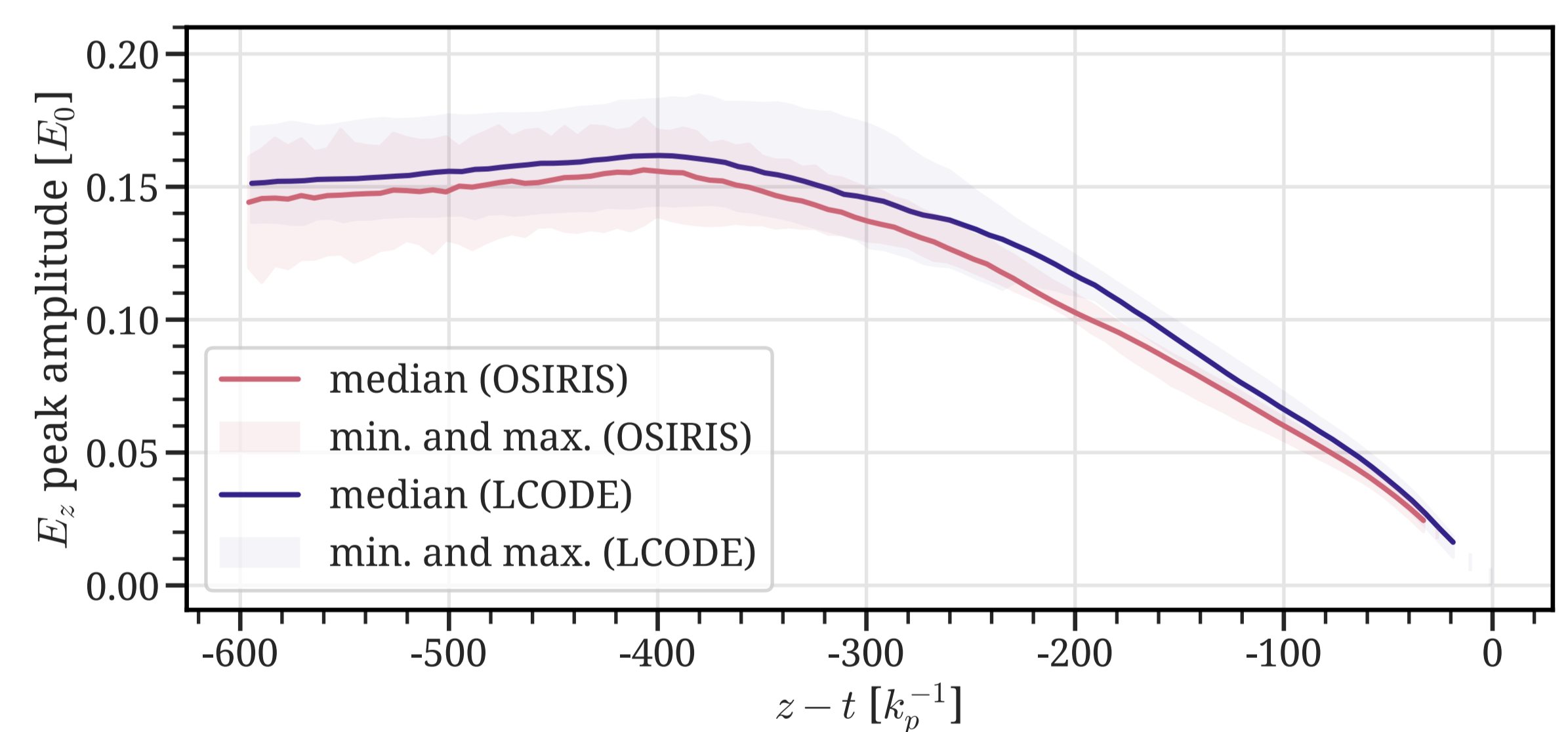
- Note that the ideal location may vary with each set of parameters → subject to **optimization studies**

How is the local wakefield amplitude measured?

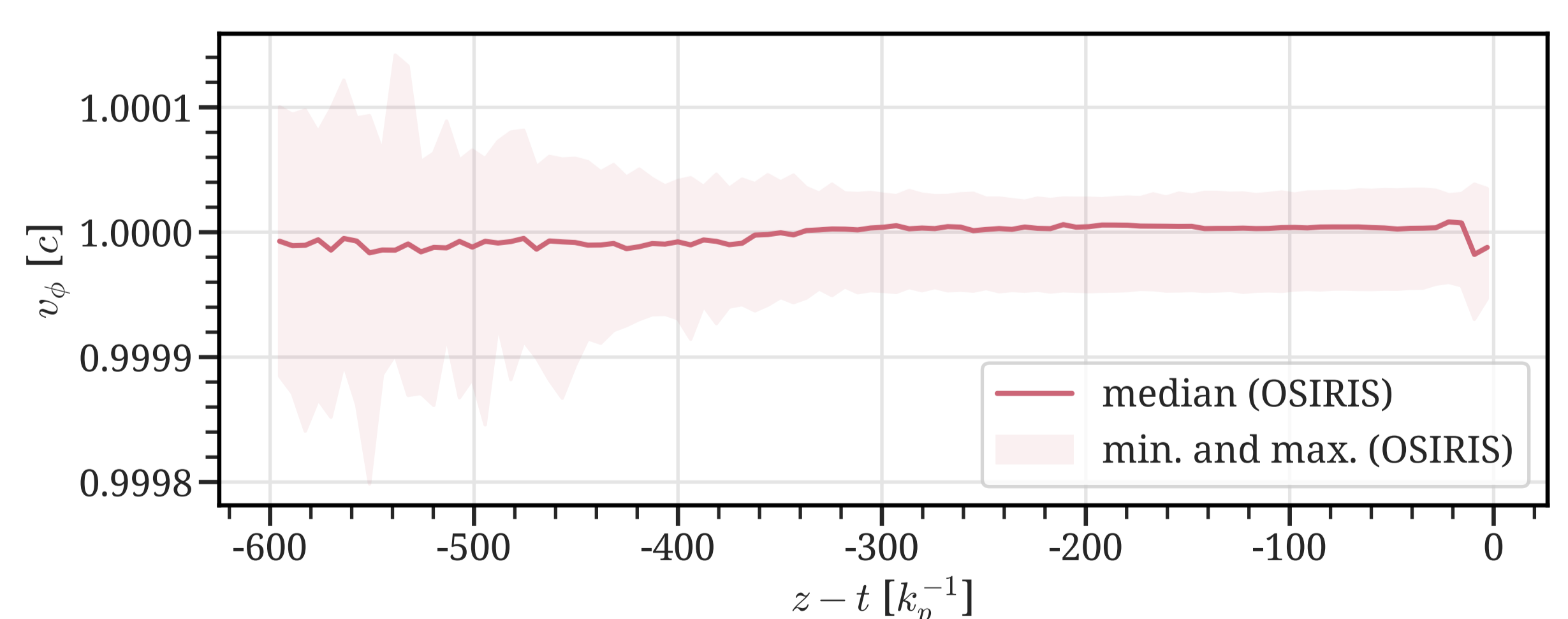
- The minimum of the on-axis longitudinal field is found **for each wakefield period and propagation distance** (blue cross symbols)



Median, minimum and maximum accelerating amplitude in accelerator plasma



Median, minimum and maximum wakefield phase velocity in accelerator plasma



Conclusions

- Realistic, complete simulations of the AWAKE Run 2c setup are challenging due to the **vastly different relevant spatial scales, large parameter space for optimization**, and open questions regarding the **experimental integration**
- A methodology has been developed to use reduced simulation models whenever possible while ensuring that important effects are not overlooked
- As part of this ongoing work, a location for injection of a test electron bunch for the RIF-seeded setup has been determined

References

- [1] E. Adli, et al. (The AWAKE Collaboration), Nature **561**, 363–367 (2018)
- [2] J. P. Farmer, et al., <https://cds.cern.ch/record/2806339> (2022)
- [3] K. V. Lotov, Phys. Plasmas **18**, 024501 (2011); K. V. Lotov, Phys. Plasmas **22**, 103110 (2015)